WHITE CLOVER

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WHITE CLOVER

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White clover (*Trifolium repens* L.) is one of the most nutritious and widely distributed forage legumes of the world. History and the presence of diverse forms in the areas indicate that white clover originated in the eastern Mediterranean countries or in Asia Minor. Its spread to other continents was rapid and apparently was associated with early colonization and the presence of domesticated grazing animals. It now is a member of the flora of every continent, where it is widely distributed. In the Western Hemisphere, its distribution extends from Alaska to southern South America.

White clover apparently was included in the "hayloft seed" that early colonists brought with them to America (*33*).[1] Historical records indicate that it was one of the first forage plants to form dense stands in pastures that followed cultivated crops or cleared forests. Being highly prolific in producing seed and having characteristics that favor dissemination, it preceded the white man into new areas. This was natural, as the small seeds are disseminated easily by wind, water, grazing animals, and birds.

White clover grows best in humid sections of the Temperate Zone during the cool, moist seasons. Periods of prolonged high temperatures with either high or low rainfall are unfavorable for its growth and maintenance of stands. It is an important forage crop in most countries within the humid sections of the Temperate Zone, e.g., Denmark, England, and Italy. The luxuriant growth of white clover is largely responsible for New Zealand's preeminence in dairying.

Today white clover in one or more of its morphological forms is the most widely used pasture legume in the humid and irrigated sections of the United States (*45*, *63*).

VALUE AND USE

The value of the white clover crop cannot be estimated accurately because of its volunteering characteristic and the seemingly spontaneous development of stands in pastures, lawns, turfs, orchards, and other areas if cultural practices permit its growth. Plants frequently appear where lime and other required minerals are present or after their application, where there is adequate moisture, and where associated grass and other vegetation are grazed or cut frequently to reduce competition for light. It is estimated that at least half of the 105 million acres of humid or irrigated pastureland has varying amounts of white clover (fig. 1). Besides its pasture value, it is esteemed by some in lawns and orchards and as a ground cover. The annual value of its seed crop in the United States is about $5,500,000.

White clover is extensively and effectively used in mixtures or alone. Its contribution to agriculture is as follows:

(1) *As a forage legume.*—It provides a highly nutritive feed as pasture, hay, and silage for livestock and poultry. Although it usually is grown in a mixture with grasses for grazing, it may be seeded alone, particularly for poultry and swine.

(2) *By fixing atmospheric nitrogen.*—If white clover is effectively inoculated with symbiotic bacteria, the amount of nitrogen made available for associated plants may range from 50 to 250 pounds per acre per year. The amount of nitrogen fixed depends on density of stand, growth produced, length and nature of growing season, soil fertility, and degree of effective inoculation.

(3) *As a cover crop.*—The growth of stolons soon after the seedlings are well established provides a ground cover that promotes soil stabilization and reduces erosion.

[1] Italic numbers in parentheses refer to Literature Cited, p. 30.

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FIGURE 1.—Mixture of clover and grass makes excellent pasture. This combination is unsurpassed as source of highly nutritious, palatable forage. It results in heavy milk production of dairy cattle, high daily gains and good carcass grade of beef cattle, and a high weaning percent for brood cows.

PLANT CHARACTERISTICS

The Seed

White clover seeds are small, approximately 700,000 per pound. Length and width are approximately equal, averaging about 1½ mm. (fig. 2). The embryos fill the entire cavity of the seed and there is no visible endosperm. The tip of the thick radicle is strongly divergent (*89*). The arrangement of the radicle and cotyledons forms a broadly heart-shaped, triangular, or oval seed. The radicle may be equal or almost equal in length to the cotyledons with the hilum between the two lobes on the end, or the radicle may be much shorter than the cotyledons with the hilum on one side in a broad, shallow indentation.

The seed surface is smooth and yellow or sometimes reddish. It changes to brown with age and weathering. The seedcoat may be impermeable, thereby causing "hard" seed. The percentage of hard seed varies among seed lots. Hard seed may remain viable in the soil for 30 years or longer (*68, 104*).

In general, seeds of varieties and types are alike. No method has been developed for reliable identification of varieties or types based on visual characteristics of the seeds.

Seeds germinate rapidly at temperatures from 50° to 68° F. Scarification and also cool night and warm day temperatures tend to cause the hard seeds to germinate (*93*). High temperatures inhibit germination. In the South, this characteristic serves as a protective mechanism by reserving viable seed for the more favorable fall months.

The Seedling Plant

The seedling is epigeal. Swelling of the cotyledons and growth of the radicle break the seedcoat. The primary root rapidly penetrates the soil, forming a slender taproot. The cotyledons and terminal bud are raised above the ground as

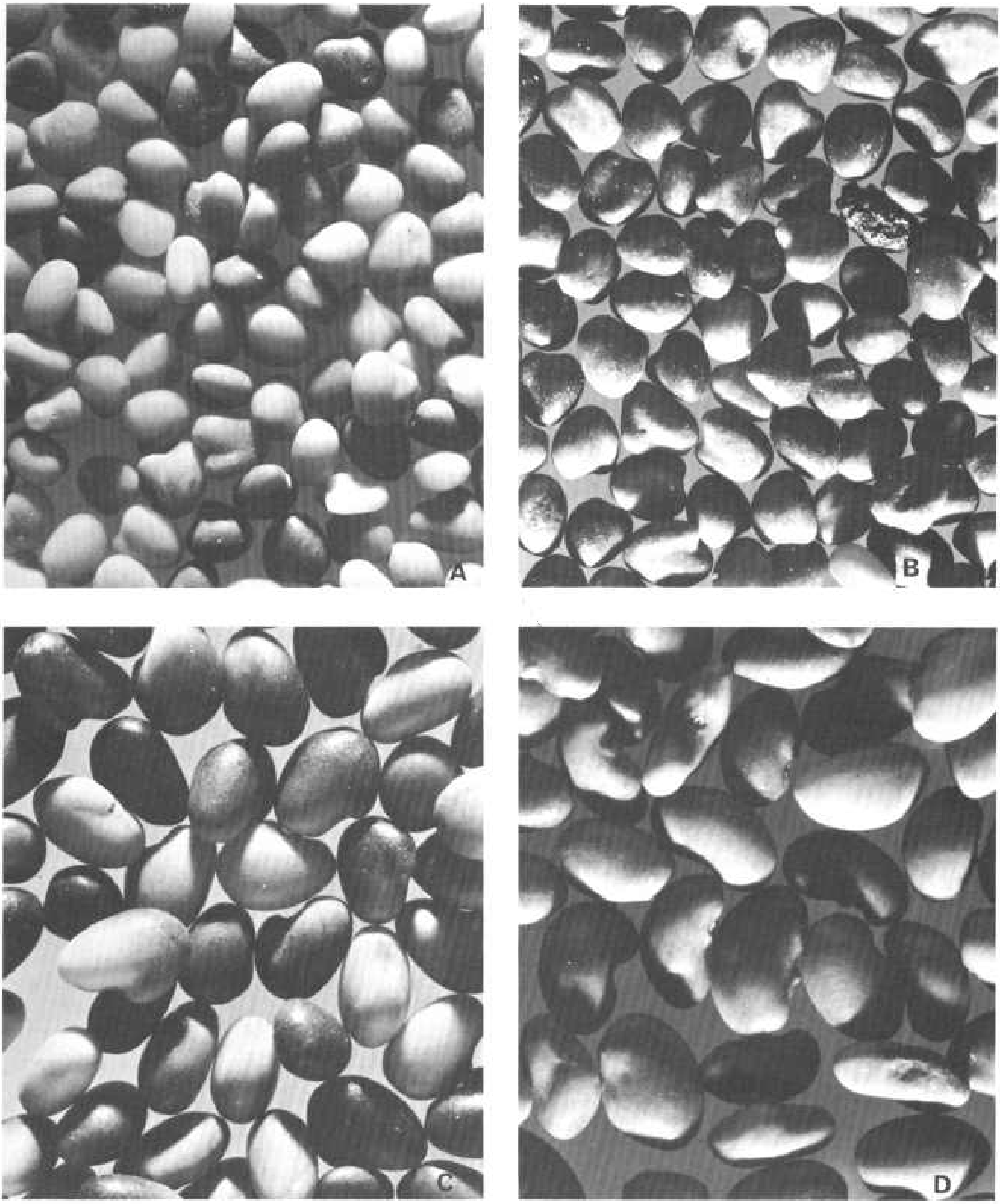

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FIGURE 2.—White clover seed compared with seed of other common forage legumes: *A*, White clover; *B*, alsike clover; *C*, red clover; *D*, alfalfa.

the hypocotyl elongates and straightens. Elongation of the hypocotyl stops after exposure and straightening of the arch in bright light. Excessive elongation of the hypocotyl may occur in greenhouses when shaded or during dull, short days of winter.

The first leaf to develop from the terminal bud is simple, but thereafter the leaves are normally trifoliolate. Leaves have progressively longer petioles until the normal length is attained. The internodes of the primary stem normally are very short. Under conditions favorable for growth, the lower axillary buds of the primary stem may grow within 6 to 8 weeks into stolons, which develop radially from the primary stem. Elongation of the primary stem stops or is limited after stolon growth begins.

The Growing Plant

Growth after stolon initiation is rapid. Leaves arising from the stolons are borne alternately, one per node. One or more adventitious roots may develop at each node. Two partially developed root initials—one on each side of the attachment of the vascular bundles of the petiole—usually protrude through the stipule. The axillary bud may remain dormant or may develop into either a branch stolon or a flower. The growth of the axillary bud depends on environment and genotype. Development of branch stolons is important in persistence of stands and continued production of leaves near the center of the plant.

Roots

The importance of the primary root rapidly diminishes. This root usually dies before or during the second year, and thereafter the life of the plant depends on the adventitious nodal roots (*100*, *109*). In general, most of the roots are in the top 6 inches of the soil, although in soil of good tilth many roots reach a depth of 3 feet. Root development during cool weather is proportionately greater than top growth (*96*). This abundant root growth during cool weather enables plants to withstand moisture stresses of the following summer.

Leaves

The trifoliolate leaves are long petioled and glabrous. Leaflets are sessile with finely serrated margins. Leaves vary widely in shape and size depending on type, variety, and environment. Normally each leaflet has a V-shaped white mark near the middle (*32*). This mark varies in intensity, size, shape, and position or may not be present at all. Also, leaflets may be variously marked with red pigment, and the number of leaflets is not always three. One supernumerary leaflet produces the "four-leaf" clover legendarily associated with good luck. The number of leaflets undoubtedly is genetically controlled; however, in most cases the expression of numbers other than three is affected by nutrition and environment.

A white clover leaf has a relatively short life. In a cool, moist environment the life of a leaf from bud to senescence is about 40 days, but is much shorter under stresses of high temperature and water deficiency. The leaf area index (LAI) of thick stands may reach a ceiling value of 5.5 twenty days after defoliation and change little thereafter (*28*). In a cool, moist environment a LAI of 5.5 is composed mostly of fully opened leaves, with smaller quantities of bud leaves and leaves in various stages of senescence. The continuous replacement of leaves enables this plant to tolerate grazing.

Stolons

The first stolons arise from axillary buds of the primary stem (fig. 3). If not obstructed, they extend radially in all directions. The stolons vary in size and length of internode. Growth is apical and indeterminate.

An axillary bud of a stolon may remain dormant or develop into either a flower or a branch stolon. The flower bud appears soon after the young subtending leaf is visible. Branch stolons appear later. The small leaves that appear at the nodes are the first leaves of branch stolons. Occasionally a small unifoliolate leaf develops instead of the trifoliolate leaf. The axillary bud at the node more nearly resembles a small seedling than does the apical bud of the stolon. These small buds are excellent for rooting. They make plants that are more like plants from seed than those made by the larger apical buds.

Since the primary stem frequently dies before or during the second year, the life of the plant soon depends on the stolons and their adventitious roots. The survival of the younger tissue serves as a natural means of vegetative reproduction. Production of branch stolons increases the chance of plant survival (*17*). Since each flower head reduces the potential branch stolons by one, branching during periods of profuse flowering is greatly reduced or not present (*103*). The precarious condition of a plant composed only of nonbranching stolons radiating from the primary stem is obvious. Defoliation will result in leafless stolons except near the stolon tips, where new leaves are forming. Stolon branching near the center of the plant provides new nodes for the replacement of leaves and aids in maintenance of uniform stands by providing meristems, which may form the centers of new plants.

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FIGURE 3.—Young white clover plant: *A*, Primary stem; *B*, stolon from basal node of primary stem; *C*, branch stolon from axillary bud. (Courtesy Clemson University.)

Flowers

Intensity of flower production varies among varieties and appears to be affected by photoperiod, temperature, nutrition, and available moisture. Flower production usually is greatest in early summer, whereas stolon branching is greatest during cool, moist periods. The flower heads are borne singularly on stems that slightly exceed the leaf petioles in length (fig. 4). The heads are mostly round and are composed of individual perfect flowers or florets, each of which is short stalked. The papilionaceous corolla is normally white and is composed of five petals. The 10 stamens are diadelphous. The one stigma is borne on a simple style. The small, normally three- to four-seeded pod is membranous and is included in the five-pointed calyx.

The number of florets per head ranges from 20 to 150, but averages about 75. These open progressively from the bottom to the top of the head in approximately a week, although the rapidity of opening depends upon the environment, particularly the temperature. The florets remain open for about 4 to 5 days or until fertilized. High temperatures shorten this period. Upon fertilization, which occurs about 18 hours after cross-pollination, the corolla collapses, and as the embryo develops the florets reflex, giving the maturing seed head an umbrellalike shape. The seeds mature in 22 to 30 days after fertilization. The time required to complete the entire process varies, with temperature exerting the greatest effect. High temperatures accelerate the process and low temperatures retard it.

Persistency of Stands (Longevity)

The most serious weakness of white clover is its frequent failure to maintain thick stands for several years (*100*). White clover is classified as a perennial, but plants may behave mostly as winter annuals in the South and as biennials or short-lived perennials in the North. Undoubtedly sev-

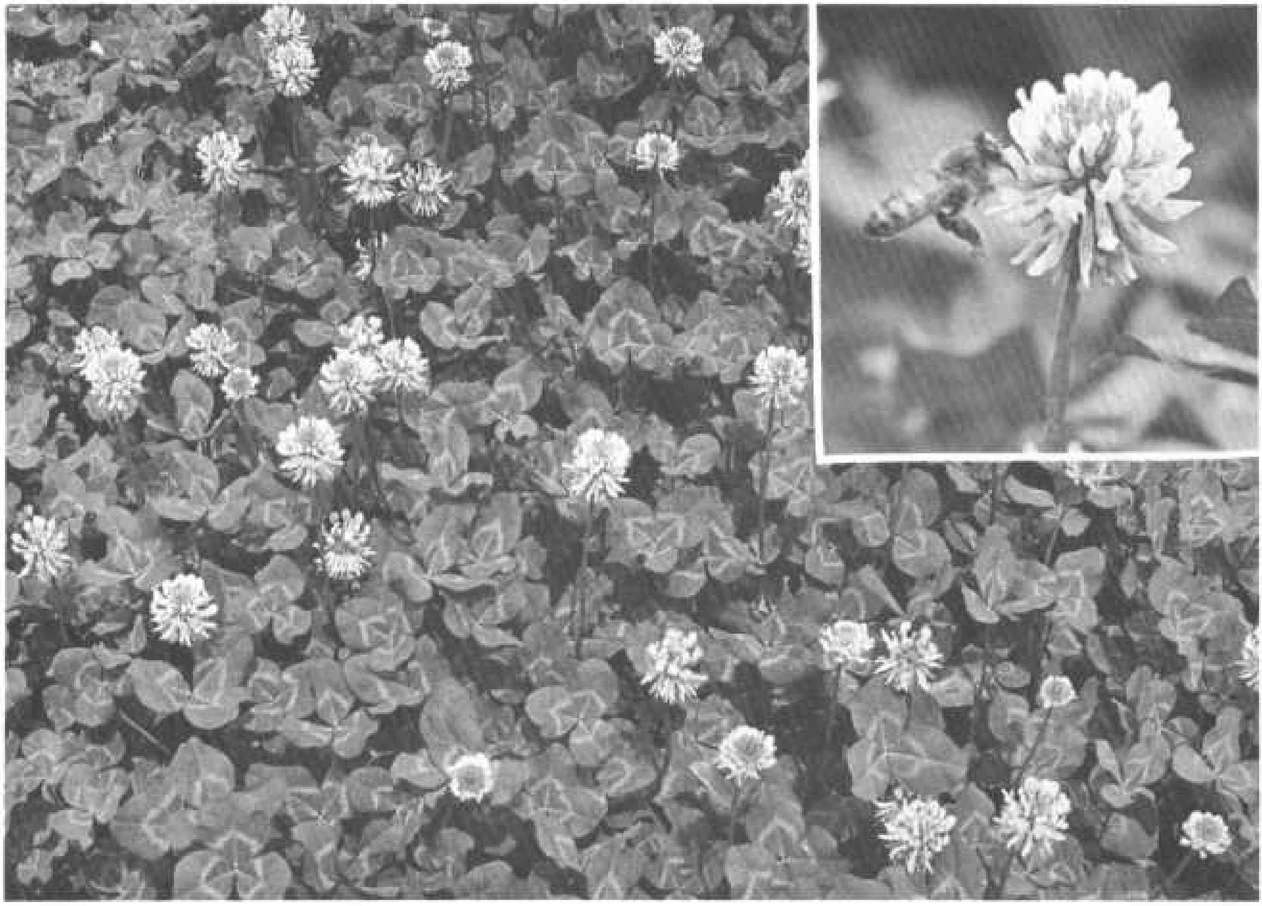

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FIGURE 4.—White clover flowers profusely if environmental requirements are met. Honey bees are best pollinators. Florets mature from bottom to top and reflex soon after fertilization. (Courtesy Clemson University.)

eral factors contribute to the thinning of stands.

The available information on the physiology, morphology, and longevity of the primary stem does not clearly establish the role and importance of this stem in the persistence of stands. Apparently the seedling taproot does not serve as a storage organ for metabolites to support growth of leaves and stolons after defoliation. Tests in the field and the greenhouse have shown that the original seedling taproots of plants in which nodal rooting was prevented by elevation of the stolons lived only slightly longer and were only slightly larger in volume than seedling taproots of plants whose nodal roots were allowed to develop normally. Elaborated metabolites and absorbed minerals translocate mostly to the young meristematic tissue of the stolons and nodal roots (*90*, *99*).

Insects and soilborne pathogenic fungi contribute to the early death of the seedling taproot (*44*, *56*). The older tissues of the taproot, nodal roots, and the stolons appear to be more susceptible to infection by destructive root and stolon rots. The taproot seldom lives longer than 2 years, even in the most favorable environment (*109*).

The primary stem does not form a "crown" that produces new growth in the second and later years as occurs in alfalfa. Most new growth comes from axillary and terminal buds of the stolons. If the primary stem persists, it contributes little. Profuse flowering and heavy seed setting, particularly under strong environmental stresses, shorten the life of the stolons (*51*).

The continued presence of white clover in a pasture may be the result of (1) annual volunteering from seed, as is the case with true reseeding annuals, and (2) vegetative propagation, i.e., growth of rooted stolons after death of the primary stem.

The maintenance of good, continuous stands of white clover over several years remains an unresolved problem. Thick stands of an established grass competing for moisture, nutrients, and light become a significant barrier to the young, developing nodal roots of the young white clover stolons, especially during periods of environmental stress. Genotypes (new varieties) that have the required morphological and physiological characteristics, together with disease and insect resistance, are needed to prolong the life of stands.

GENETICS AND CYTOGENETICS

White clover is a tetraploid (2n=32 chromosomes). It is normally self-incompatible. Disomic inheritance and the prevalence of regular pairing and disjunction of the chromosomes in meiosis indicate that it is an amphidiploid (*8*). At least 64 oppositional "*S*" alleles have been identified. This number is well above the minimum required for a high degree of seed setting. A fertility factor "S_f" is a member of the allelomorphic series. Plants having this factor are self-compatible. The ability of some plants to set seed following selfing without the S_f allele has been designated as pseudoself-compatibility. Thus, plants may vary from complete self-incompatibility through intermediate grades of pseudoself-compatibility to a high degree of true self-compatibility.

Eleven variations of the white V-leaf marking have been reported (*25*). This mark is conditioned by an allelic series. Red leaves, red flecking, red midrib, and a red spot are other hereditary leaf characteristics that have been described. These, as is true of the white V, are dominant to no mark and are simply inherited.

The presence of HCN (hydrocyanic acid) in white clover depends on the presence of the precursor glucoside and the hydrolyzing enzyme. Both glucoside and enzyme are determined by separate single dominant factors, which segregate independently.

The recent successful species hybrids *T. repens* × *T. nigrescens* Viv. and *T. repens* × *T. uniflorum* L. have opened the door for the plant breeder to variation beyond that existing in the species (*66*, *91*). Improved techniques for growing excised embryos and the use of grafts may extend the range of usable variation to additional species (*46*).

The inheritance of qualitative characters in white clover is summarized in table 1.

TABLE 1.—*Summary of inheritance of qualitative characters in white clover*

Character [1]	Symbol	Inheritance
FLOWER		
Cyanidin-red corolla, black seed (*24*)	C^1/c^1, C^2/c^2	Pigmentation $= c^1/c^1$, c^2/c^2.
Blush-colored corolla (*24*)	B/b	Blush $= b/b$.
Nonclasping bracts (*24*)	Br/br	Nonclasping $= br/br$.
Vestigial florets [2]	Vg^1/vg^1, Vg^2/vg^2	Vestigial florets $= Vg^1/-$, $Vg^2/-$.
LEAFLET		
Red leaf (*25, 32*)	R^1/r	Red leaf $= R^1/-$.
Red flecking (*25, 32*)	R^f/r	Flecking $= R^f/-$.
Red midrib (*25, 32*)	R^m/r^m	$R^m/-$.
Mottling (virosis) (*9*)	M^1/m^1, M^2/m^2	Mottling $= M^1/-$, $M^2/-$.
White V (varies in location and expression) (*25, 32*)	$V \ldots v$	Multiple alleles; v/v = solid green.
Red spot (controlled by or closely linked to V locus) (*67*)	V^r2/v^r2	$V^r2/-$.
CHEMICAL OR PHYSIOLOGICAL CHARACTERS		
Self-incompatibility (*5*)	$S_1S_2 \ldots Sn$	Multiple alleles.
Cyanogenetic glucosides (*10*)	Ac/ac	Presence of glucosides $= Ac/-$.
Linamarase (enzyme) (*10*)	Li/li	Presence of enzyme $= Li/-$.
HCN (*10*)	----------------	Presence of acid $= Ac/-$, $Li/-$.

[1] Numbers in parentheses indicate references in which inheritances of characters are reported.

[2] Based on authors' unpublished preliminary data.

BREEDING

Breeding techniques must be adapted to the characteristics of white clover and to its use.

Frequent reference to the species as being highly polymorphic or heterogenous recognizes the existence of great variation (*2*, *61*). Differences in morphological characteristics are obvious. Other differences, such as variation in chemical composition and reactions to diseases, insects, different temperatures, photoperiods, and moisture stresses, are less obvious but may be more important from the breeding aspect.

Several species of bees and other insects pollinate

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FIGURE 5.—Plant breeders may use honey bees for controlled pollinations by placing small hives inside cages. Lights may be used above plants to induce uniform and abundant flowering. (Courtesy Clemson University.)

white clover (*23*). Honey and other bees may be used under cages to produce the amounts of seed needed in a breeding program (fig. 5). Heterozygous genotypes can be maintained or increased easily by vegetative propagation. The reproduction and other characteristics of white clover are such that it is well adapted to the polycross method of testing the combining ability of clones.

The ability to tolerate competition is necessary for the continued existence of a white clover plant growing either in pure stands or in association with a grass. Since white clover is used almost exclusively in association with a grass, selections and evaluations should be made by studying the clover in a stand of the grass with which it will be used.

Since the most common criticism of white clover is the loss of stands in pastures, improving persistence is a logical goal of most white clover-breeding programs. Because many factors contribute to persistence, one needs to first determine the relative importance of these factors. Then, appropriate specific objectives can be used, e.g., resistance to a specific pathogen. Increased production, at least of older stands, should accompany improvement in persistence.

Characteristics of white clover that affect the choice of techniques and methods to be used in developing improved varieties are as follows:

(1) Plants are highly self-incompatible—enforced by a series of S alleles.

(2) Plants are highly heterozygous as a result of enforced cross-pollination.

(3) Selfing is possible by using either the S_f gene or the pseudoself-compatibility characteristic.

(4) Plants normally bloom and set seed every year.

(5) Flowering for making crosses may be induced easily in the greenhouse.

(6) Hand pollinations are easy to make and result in a good seed set.

(7) Vegetative propagation to the extent needed in a breeding program is easily done by rooting stolons.

(8) Plants of clones may be grown and maintained in the greenhouse in 6-inch pots or smaller containers.

Source Nurseries

Screening diverse germ plasm is essential. In this screening program, collections from areas having growing conditions that approximate the environment in which improved varieties will be used should be investigated extensively.

One method of screening seed lots consists in planting broadcast with a competing grass, clipping to simulate grazing, then selecting superior plants after the occurrence of environmental stresses of magnitudes that cause differential survival.

Plants selected from old stands and from source nurseries frequently are infected with one or more viruses. Seedling plants normally are virus free. The virus status of plants must be considered in their evaluation.

Plants selected for further evaluation as clones should have medium-size stolons that branch frequently and should flower sparsely in the environment where the variety will be used for forage (*53*).

Evaluation of Clones

Phenotypes selected from broadcast-planted source nurseries or other sources, such as old pastures, are subjected to varying degrees of evaluation. These selections generally are increased vegetatively and established (1) as spaced plants for specific characterization or (2) in small plots or beds—propagules interplanted on narrow centers with a grass to simulate a pasture (*7*). The plots are managed to provide evaluation of the clones growing with a grass under environmental stresses.

Bee cages may be used to produce seed for clonal evaluations. Cages are necessary, because white clover is so widely and generally distributed that the use of isolated crossing blocks is rarely feasible. Hand pollinations are seldom used because of the time required to manipulate the small floral organs and because of the number of seed needed to establish plots. Since it is often necessary to minimize the use of bee cages, white clover breeders compared to breeders of many other crops probably put more effort into reducing the number of clones to be evaluated by test crosses. The correlation between the responses of parental clones and those of their progenies indicates that this can be done. Evaluating selections first by planting as spaced plants then by planting on narrow centers in plots permits progressive elimination of inferior germ plasm.

Concurrently with the field evaluation of clones by plantings of propagules, the clones should be screened in the greenhouse or laboratory for as many characteristics as possible, such as resistance to specific diseases (fig. 6). Considerable progress has been made in recent years in developing techniques for locating resistance to soilborne pathogens and nematodes (*58, 59*).

After careful elimination among the original selections, based on observations and measurements in replicated tests, progenies of the remaining clones are compared. Polycross progeny testing usually is employed because it combines economy

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FIGURE 6.—Greenhouse screening to obtain plants resistant to root-knot nematodes. Left, susceptible white clover plants; right, resistant plants. (Courtesy Clemson University.)

of effort with estimates of combining ability and performance in synthetic varieties (*69, 105*). This is accomplished by choosing a number, usually between 10 and 20, of superior clones that flower at the same time and planting these in a crossing block. Polycross seeds from each clone are harvested and used to determine the combining ability of the clone.

Results of recent research indicate the feasibility of greater use of single crosses or clonal crosses. Small plots of a clover-grass mixture established by check-planting clover seedlings on 6-inch centers and by broadcast seeding the clover gave similar results (*52*). Thus, by setting seedlings in the field, a small quantity of seed is adequate to evaluate a strain of clover (*41*). The individual plants may be classified for growth type and some other characteristics before they grow together to form a solid stand. Establishing plots by transplanting seedlings makes feasible the use of hand pollinations to produce seed for strain evaluations.

Synthetic Varieties

Superior clones may be combined into an experimental synthetic variety. In white clover this can be done easily by planting the clones together in a crossing block. The bulk seed is harvested for testing or increase in successive generations. Ultimately the evaluation program should include plantings of seed of the generation to be used in the seed trade. The parent clones can be maintained indefinitely by vegetative propagation. However, prior to the release of such a variety it is desirable to make diallel crosses of the parent clones to avoid the use of clones that in specific combinations produce inferior plants.

Mass Selection and Natural Selection

Mass selection is a plant-breeding procedure that may employ various artificial, or manmade, selection pressures in addition to those of nature. The breeding procedures referred to as "strain building" and "maternal-line selection" may logically be considered modifications of mass selection. These procedures include a continuous synthesis of a strain by various methods of breeding (*105*).

The variability in the species plus the high degree of cross-pollination favor shifts in response to natural or artificial selection pressures. Strains of white clover have been naturally and artificially made and maintained under specific environmental conditions. Many ecotypes exist. Some have made valuable contributions as local varieties. Management practices may be employed in a given environment to create selection pressures and thus maintain varietal characteristics.

Inbreeding

Selfing is possible by using the S_f gene or the pseudoself-compatibility characteristics. Inbreeding results in the appearance of chlorophyll deficiencies, leaf abnormalities, and other offtypes similar to those that have been obtained by inbreeding other normally cross-pollinated crops. The use of inbreeding in white clover breeding has been limited. It should be explored to determine its ultimate value (*4*, *6*).

First-Generation and Double-Cross Hybrids

The ease of vegetative propagation and the prevalence of self-incompatibility make first-generation and double-cross hybrids definite possibilities. If hybrids are used, their performance must justify the additional expense involved in seed production. To date, such a hybrid variety has not been developed.

Induced Polyploidy and Species Hybridization

The use of induced polyploidy in white clover improvement has been attempted. An experimental variety $8x=64$ developed at the Vermont Agricultural Experiment Station was widely tested but never released. Probably the greatest contribution of polyploids is the increased possibility of fertile crosses with other species. A fertile F_1 from the cross $8x=64$ *T. repens* × $4x=32$ *T. nigrescens* has been obtained (*26*, *66*). Although this cross has not contributed to an improved variety, it is proof that species crosses are possible in the genus *Trifolium*. The development of improved techniques for handling excised embryos offers greater possibilities for making wide crosses and for obtaining desired characters from other species (*70*).

Mutational Breeding

Changes in white clover chromosomes have been induced by radiation and other mutagenic agents. The use of mutagenic agents on other plants has produced predominantly deleterious changes. On the other hand, a few changes have been considered desirable. Regardless, the number of varieties containing changes attributed to induced mutations is small and their acceptance or use has been limited. It seems logical to explore thoroughly existing variability prior to trying haphazard-induced mutations.

Varietal Release and Seed Increase

Procedures for the orderly release, increase, distribution, and maintenance of varieties have been developed in most countries and States. These are applicable to white clover. The desirability of a variety with a wide range of adaptation is evident. This is especially true for varieties of which seed must be produced outside the area of utilization. This frequently applies to white clover varieties. A wide range of adaptation and the resulting greater demand for seed favor a greater, more economical, and more reliable seed supply.

Techniques

Emasculation, Pollination, and Seed Production

Emasculation is not necessary in much of the crossing included in a breeding program. Emasculation should be practiced in making critical crosses or when working with self-compatible plants. Several emasculation techniques have been successfully used. The two best known are removal of the anthers by suction and with forceps.

One of the most rapid methods consists in (1) removing all open florets from a young flower head, then removing all florets above the whorl of florets that are about to open; (2) seizing the corolla on the underside at a point midway between the tip of the calyx and the tip of the standard, using only the tip of the forceps; and (3) withdrawing the entire corolla together with the staminal tube and all anthers by pulling slowly and steadily. The stigma is left exposed and ready for pollination. By using this technique, emasculation and pollination can be performed as quickly as pollination without emasculation. To reduce the chance of selfing as a result of anthers dehiscing during emasculation, the stigmas may be atomized with water immediately after emasculation and pollination delayed until the stigmas have dried (*111*).

An ordinary lead pencil is convenient for transferring pollen. The pollen can be easily seen on the black lead.

Bee cages are used to produce polycross seed and seed of crosses if the amount needed is more than can be produced by hand pollinations. For convenience in maintaining plant identities, the area to be covered by the bee cage may be divided into "cells" by using boards or pieces of sheet metal for low partitions that confine the plants but do not obstruct the bees. One plant is then set in each cell. Slight differences in time of flowering may be corrected by (1) letting plants grow until flower buds are forming on plants of all clones, (2) removing all flower heads containing open florets, (3) erecting the cage, and (4) moving bees into the cage when plants of all clones have open flowers.

In addition to these steps, the authors have used electric lights inside the cages to induce more flowering. The lights are set to extend the natural daylight to about 16 hours. This has given a flush of flowers during the time the bees are used. Seeds are harvested about 28 days after the bees are removed.

Induction of Flowering

Flowering is affected by temperature, moisture stress, light intensity, day length, and the age, condition, and genotype of the plant (*14*, *27*, *102*). The authors have induced flowering in the greenhouse both by interrupting the night period by 1 hour of light and by extending the daylight period. The photoperiod required for flowering varies from 13 to 16 hours depending on the genotype of the plant (*82*). Some plants will produce one flush of flowers and then produce few if any more; other plants will produce flowers over a period of time.

Vegetative Propagation

Vegetative propagation merely consists in rooting stolon pieces in sand, soil, or rooting media. Plant hormones to stimulate rooting are not needed. Stolon tips or stolon segments with developing vegetative buds are preferred; however, other segments will root. A satisfactory procedure that results in a high percentage of uniform plants is as follows: Take stolon tips including three internodes, remove all leaves except the terminal one, and place the stolons in sand, the cut end about one-half inch deep and the bud end on the surface. If a layer of soil is used under the sand, the cuttings can be left in the sand until several new leaves are formed prior to transplanting.

Propagation With Seed

Germination of freshly harvested white clover seed varies. In addition to hard-seeded dormancy, some seeds apparently require a period for post-harvest maturation. Germination can be increased by scarification and by altering the temperature (*93*).

The seeds may be germinated on blotter paper and moved to the soil as they germinate and before the roots become tangled. This method is very satisfactory for handling small numbers of seed. Larger amounts of seed probably can be more efficiently handled by planting on soil, covering with sand, and transplanting to small pots at about the time the third trifoliolate leaf appears. Ground sphagnum moss may also be used instead of soil, or a ¾-inch layer of sphagnum moss may be placed on the soil. Sphagnum moss reduces seedling loss caused by the damping-off diseases.

Plants kept in greenhouses for seed production should be in 6- or 8-inch pots. Plants to go into the field may be started in pots as small as 2½ inches.

Field Plots

The ultimate goal of improvement programs is to develop a variety superior in such characteristics as total production, seasonal distribution of production, and persistence under competition. Field plots should permit evaluation of selections and varieties in regard to their yield and persistence when grown in association with a grass. Plots about 5 feet by 5 feet have been used by the authors to evaluate both seedlings and propagules. These plots were separated by grass alleys and had little if any border effect. However, if larger plots are preferred, dimensions of 5 by 20 and 10 by 20 feet are frequently used. However, the final evaluation should be based on large plots grazed by animals.

Measuring Yields

Rotary mowers equipped with catch baskets permit yield determinations at frequent intervals during the growing season. They enable one to simulate grazing more closely and to measure the distribution of production more accurately. Sickle mowers equipped with catch baskets may also be used and may be necessary if large plots are used.

Since part of the clover's contribution to forage production is to furnish nitrogen for the grass, measurement of the combined yield of the clover and grass is sometimes made. Botanical separations are expensive, but may be necessary in critical tests. Preferably, seedings for varietal yield evaluations should be made both with and without a grass.

Height and frequency of cutting have been studied by several investigators (*31*, *97*). Close, frequent clipping favors the clover. The authors consider that clipping at a height of 3 inches above the soil surface at 4-week intervals throughout the growing season is satisfactory for most tests.

Measuring Stands

Stands may be estimated or measured by various techniques. Visual estimates have been used successfully, as well as an adaptation of the line transect. This latter technique consists in determining the average number of live stolons transecting a meter line in the test area. It recognizes the stolon as the source of growth. The measurements may be made in pastures or in plots. The number of leaves present does not affect the reading. Measurements may be made after harvesting plots or in grazed pastures.

Alternate Approach to Improvement

The discussion of breeding white clover for increased persistence of stands as a perennial does not preclude the possibility of breeding as an annual, with or without natural reseeding. For some areas or uses, breeding as an annual may be the correct approach. Also, it has the advantage of starting annually with a large part of the clover population being virus free. Much of the previous discussion is applicable, with only slight modification, to breeding as an annual.

TYPES AND VARIETIES

Types

The great range of morphological forms in white clover is recognized in the classification into the agronomic types—small, intermediate, and large. These are represented by the varieties Kent Wild White, Louisiana White, and Ladino,[2] respectively (*63*). This classification was particularly valuable in describing early varieties and ecotypes. Care must be exercised in attempting classification by type, particularly under some environmental conditions, such as optimum temperature and moisture and a short winter photoperiod in a greenhouse. Variation in size characteristics of plants is continuous. Differentiation between the larger plants of an intermediate type and the smaller plants of a large type is almost impossible.

Since types intercross freely and do not have specific limits, classification problems are common (*2*). For example, a plant may have the large leaf and flower-head characteristics of the large type but stolons belonging to the intermediate type. An intermediate-type variety that has been grown for an unlimited number of generations and has been subject to outcrossing may have some plants of both large and small types. Seed lots of both the small and the large types may have some plants belonging to the intermediate type. A field classification, by the authors, of several hundred plants of a naturalized intermediate Louisiana variety gave approximately 7, 65, and 27 percent of large, intermediate, and small types, respectively.

Varieties

There are not many varieties of white clover of United States and Canadian origin, and many of them are ecotypes and are not bred varieties of a specific plant-breeding program. Two variety names used in writings and advertisements are misleading and erroneous. These are Dutch White clover and Wild White clover. Both names were used by the seed merchants in the 19th and early 20th century, probably for customer appeal. The name "Dutch" was applied to any white clover, the seed of which was produced in the Low Countries. Such seed has not been imported into this country in quantity for many years. Dutch in common usage is a synonym for Common White, which may be any one of the three "agronomic types" or mixtures thereof.

[2] The U.S. Department of Agriculture Service and Regulatory Announcement No. 156, issued March 1940 and reprinted with amendments June 1960, lists ladino as a kind of clover not a variety. The Crop Science Society of America recognizes that ladino is used also as a varietal name and distinguishes this usage by capitalization. In this publication, ladino is considered a variety of white clover. This usage has been followed in the U.S. Department of Agriculture Yearbooks.

The term "Wild White" apparently originated in Great Britain and was used there to designate the small type. The connotation that Wild White is the prototype of white clover cannot be substantiated. Wild White clover most likely arose from the survival of the fittest in pastures under the continuous selection pressure of close grazing by domesticated animals.

Studies of plant characteristics have been made in efforts to delineate the Ladino variety from intermediate-type varieties, particularly in the advanced seedling stage. Length and diameter of leaf petiole, size and shape of leaflets, and number of petiole vascular bundles have been studied. Not one of these characteristics has been a satisfactory index for differentiation. Diameter of the leaf petiole has been the most consistent characteristic of those studied under specific environment and management practices. Growth responses to variations in nutrition, soil moisture, temperature, frequency of defoliation, and photoperiod may make classification difficult. For example, Ladino when defoliated to simulate a lawn may produce short, stubby leaf petioles.

Although there are a large number of foreign varieties of white clover, most of them do not appear on the domestic market in quantity and will only be mentioned by name, origin, and type. Most of these foreign varieties are not adapted to the environments of the United States nor to the management practices in use.

Variety Adaptation

Many factors contribute to variety adaptation. Diseases, insects and other pests, climate, photoperiod, soil, and management collectively determine whether a variety is superior, similar, or inferior to others when planted in comparative tests. Only by testing varieties over a period of years can the superior ones be identified. Even within a single State, the use of more than one variety may be necessary.

In the search for superior germ plasm, most white clover varieties and many common seed lots of worldwide origin have been and are now being tested extensively in the United States. With the exception of Ladino, none have given superior performance or have proved to be widely adapted when compared with those of domestic origin. Occasionally a foreign variety may be outstanding in a very restricted area. For example, New Zealand white clover is productive and persistent in northwestern Oregon. Its resistance to injury from slugs and its adaptation to the cool, moist climate of the area appear to be the principal reasons for its superiority.

Even within the United States the varieties originating in the Northern States are not adapted to conditions of the lower South. In the shorter photoperiod, they flower sparingly, produce insufficient seed for volunteering, and produce low yields of forage when adapted varieties are making their most rapid growth. As varieties adapted to the South are moved northward, they flower profusely and early. Later vegetative development is stimulated by the longer day. They are adversely affected by low winter temperatures. The incidence and severity of root and stolon rots are earlier and greater after profuse flowering.

Variety recommendations are the function of State agricultural experiment stations, which in their research programs conduct variety tests under the different soil and climatic conditions of their respective States. Such tests should be conducted before a variety is officially named and released for commercial seed production. This practice is highly desirable as it synchronizes seed availability with farm demand. Since varieties are continually changing as new, superior ones replace older ones, many State agricultural experiment stations annually publish a list of those recommended.

Description of Varieties

White clover varietal distinctions have only become important since 1935. The continued common usage of the terms "Dutch White" clover and "Wild White" clover is a vestige from the time when there were few varieties.

Common White

Common White as the name implies is indeed common. The seed may come from any source. In general, the plants are of the intermediate type. Practically all the so-called varieties given State names originated from plantings of such seed. Unadapted seed planted in a State and harvested for seed unfortunately may be labeled as a naturalized State variety where grown, even though it is inferior.

State-Named Varieties

Of the so-called State varieties, Louisiana White is the best known. This is a natural consequence of the position Louisiana holds in white clover seed production. Although plants from a seed lot of Louisiana White clover are predominantly of the intermediate type, some plants may be of the large or small type or both types. The frequencies of the different type plants vary among seed lots. The planting in Louisiana of seed from different places of origin and natural selection under different management practices account for much of the variation.

Louisiana White plants flower profusely throughout the South. Seed production is ample for a volunteer crop even under close grazing.

As a result of the very general requirements for white clover seed to be classified as Louisiana White, various producers and groups of producers have applied their names or brand names to seed that otherwise would be sold as Louisiana White. Some of these seeds are produced on large acreages maintained by following management practices that should insure a maximum purity of plants of a desirable size adapted to the southern climate. Nolin White maintained near Hamburg, La., is an example.

Louisiana S1

Louisiana S1, a synthetic variety, was developed at the Louisiana Agricultural Experiment Station and is very similar to Louisiana White (fig. 7). The five parental clones were selected from a source nursery of Louisiana White plants. The principal objective of the breeding program that culminated in the release of this variety was to increase heat and drought tolerance.

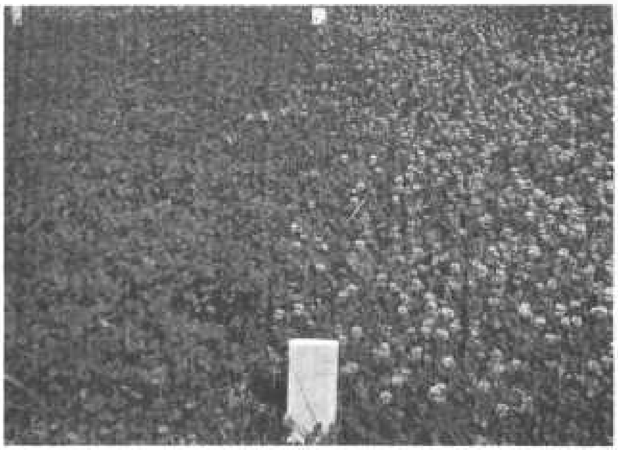

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FIGURE 7.—Left, Ladino clover; right, Louisiana S1. Note absence of flowers on Ladino. Short photoperiod in lower South prevents flowering and seed production of northern white clover varieties necessary for volunteer stands in fall. Picture taken April 12.

Regal

Regal is a synthetic variety of five clones selected for persistency, vigor, and sparse blooming under Alabama conditions. This variety, developed at the Alabama Agricultural Experiment Station, was released in 1962.

Ladino

Ladino, as recorded in 1848, was first found growing on an estate in the Po Valley of Italy. The first record of its introduction into the United States appears to be in 1891 (*81*). Introductions occurred between 1900 and 1910, but the first significant establishment of Ladino fields occurred in the Western States in 1912.

Ladino is a variety of the large type of *Trifolium repens* (fig. 7). In general, all its vegetative parts are larger than those of intermediate white. There is no difference in seed size. The considerable variation in size characteristics has probably resulted from outcrossing with the intermediate and small types. F_1 plants from crosses of Ladino and plants of the small type are intermediate in size.

Observations by the authors over a period of years on spaced-plant populations of domestic and Italian lots of Ladino indicate that the diameter of the stolons of the lots of domestic origin is slightly smaller than that of lots of Italian origin. This could have happened through selection pressure from the tramping of grazing animals, since most of the early Ladino seed fields in Oregon were grazed several times each year. In Italy, practically all the Ladino is harvested as green feed and thus eliminates any injury to plants with large stolons. It should be noted that Ladino originated in Italy at approximately 45° N. and that it first flourished in the United States at approximately 43° N.

Merit

Merit is a synthetic variety of 30 clones selected from Ladino. After 3 years of testing under Iowa conditions, it was released by the Iowa Agricultural Experiment Station in 1961. Although Merit is similar to Ladino in appearance, in Iowa it has shown superiority in forage yield, winter survival, and summer drought tolerance.

Pilgrim

Pilgrim is a synthetic variety of 21 clones originating from seed collected from older Ladino pastures in the Northeastern States and Canada. The selected clones were progeny tested for the large-type characteristics. It was named and released in 1953 by several northeastern State agricultural experiment stations, the U.S. Regional Pasture Research Laboratory, and the Division of Forage Crops and Diseases, U.S. Department of Agriculture. The Nursery Division, Soil Conservation Service, assisted by producing the first breeder seed from a clonal planting. The principal objectives in the development of Pilgrim were to purify a seed stock of the large type and to establish a continuing source of breeder seed of the same genetic composition. The clones are maintained and breeder seeds produced under the auspices of the Washington Agricultural Experiment Station.

Espanso

Espanso, formerly called Granladino, was developed in Italy. It is claimed to have improved winter and drought tolerance together with good persistence. Plants are of the large type.

Nordic

Nordic was developed in Germany from a cross between Ladino and Morso, a Danish variety. It is being grown in the United States for the export seed trade.

New York Wild White

New York Wild White was grown and used in New York. It was a naturalized small-type variety selected from an old pasture that was continuously and closely grazed. It is no longer used.

Foreign Varieties and Strains

For many years the U.S. Agricultural Research Service has collected and distributed seed for testing. Many foreign sources have been included in this search for superior germ plasm. Some of these collections, with their sources, are as follows:

Australia: Caboolture, Dingee, Garlanton, Giganteum, Irrigation, Mankland, Mary R., Namlesur, Nappan Wild, Pyramid, Redcliffe, Reeli Ck., Sanford, S. Maroochy R.; **Canada:** Canadian Ladino Synthetic; **Denmark:** Adefa II V., Adefa IV, Daehnfeldt, Daeno II K., Danish Stryne, Ladino Synthetic, Lodi I., K., and V., Lodi Otofte, Lodi Otofte I., K., and V., Milka, Morso, Morso Otofte, Morso Otofte I. and K., Pajbjerg Milka; **Finland:** Kemi; **Germany:** Nordic; **Great Britain (England):** Bedfordshire Wild, Cotswold Wild, East Anglia, Essex Wild, Kent Wild, Kersey, New Suffold, Northants Wild; **Great Britain (Wales):** Aberystwyth S.100, Aberystwyth S.100 (Nomark), Aberystwyth S.184; **Holland:** Cultnur Klaver-CB leg type, De Weledelzear CB, Witte Weideklavar CB, W.M.K. 46.12, W.M.K. 47.7, W.M.K. 47.9, W.M.K. 47.10; **New Zealand:** Certified, Certified Mother, New Zealand, Pedigree, Permanent Pasture, Wild; **Sweden:** Hero, Nora, Robusta, Svalof Kivi, V. 22.

Many more seed lots from these and other countries have been introduced and examined. They have been obtained from the New Crops Research Branch of the Agricultural Research Service, the Soil Conservation Service, and foreign and domestic members of the seed trade.

DISEASES[3]

Several pathogens attack white clover, reducing its quality, yield, and persistence. Pathogens attacking leaves produce conspicuous symptoms; however, foliar diseases are usually not so destructive as diseases of roots and stolons.

Only the most prevalent and economically important diseases are discussed (*75*). With few exceptions, they are widely distributed in the United States. Their prevalence depends on many factors, including presence of susceptible plants, favorable temperature and moisture conditions, age of plants, and for some virus diseases, presence of suitable vectors.

Pepper Spot

Pepper spot is incited by the fungus *Leptosphaerulina trifolii* (Rost.) Petr. The disease is most prevalent and destructive during cool, wet weather. In the Northern States, infection may occur throughout the entire growing season. In the South, it is most prevalent and destructive during the winter and spring (*49*).

Tiny, black, sunken spots develop on leaves and petioles, hence the name pepper spot. The spots may become so numerous that infected leaves appear darkened or grayish (fig. 8). The tiny spots rarely enlarge beyond a millimeter or two. Diseased leaves rapidly turn yellow, wilt, and die during warm weather. Although related biotypes of the fungus attack other legumes, the biotype attacking white clover is largely restricted to *Trifolium* spp. (*54*). The fungus survives in specialized fruiting structures on dead leaves and petioles during periods of the year unfavorable for infection.

Lines more resistant to the disease are being developed. When heavy infection occurs, removing diseased foliage by grazing or mowing helps to reduce infection on new growth.

Cercospora Leaf and Stem Spot

Cercospora leaf and stem spot is caused by the fungus *Cercospora zebrina* Pass. The disease occurs on white clover throughout its range of adaptation and in some seasons it can be very prevalent and destructive. The disease is particularly se-

[3] Prepared by K. W. Kreitlow, research pathologist, Crops Research Division.

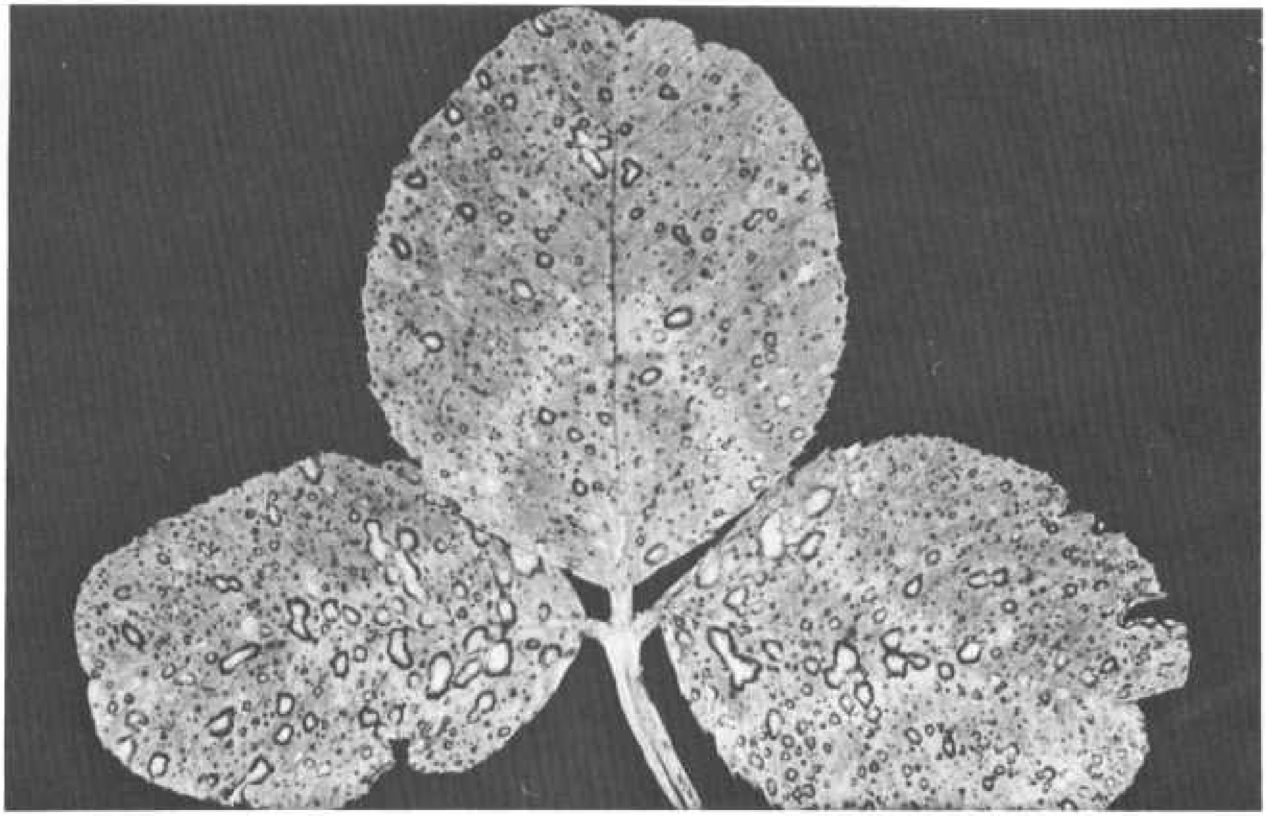

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FIGURE 8.—Advanced stage of pepper spot infection on Ladino white clover leaf. Pepper spot is one of widespread serious leaf diseases that reduce growth and longevity of leaves.

vere on white clover in the South during the summer and early fall (*65*). Infection occurs throughout the growing season on plants of any age.

Leaf lesions are usually rectangular and more or less limited by the veins. They vary from light brown to purplish black. When dew is still on the leaves, the lesions appear silvery from the numerous spores produced by the fungus. Lesions on stems are usually somewhat sunken and dark. New infections result from spores spread by air currents and rain. Heavy infection causes leaves to wither prematurely. Cercospora spores from white clover can infect red and alsike clovers and possibly other species of legumes as well (*19*).

There is little information on the control of Cercospora leaf and stem spot. Removing old crop residues, combined with crop rotation, helps to reduce damage. Clipping or grazing when the disease appears destructive may reduce damage to succeeding crops (*42*). Newer varieties usually have been selected for greater resistance to the disease (*75*).

Curvularia Leaf Spot

Curvularia leaf spot is incited by *Curvularia trifolii* (Kauff.) Boed. It causes wilting and dying of leaves. Ladino white clover seems to be more susceptible to infection than varieties of the intermediate type. The disease is most prevalent during warm, humid weather, when 20 to 25 percent of the leaves may be attacked and damaged (*79*).

Diseased leaves are usually characterized by the presence of a large yellowed area that turns watery gray to tan, translucent, then light brown. A yellowish band generally outlines the advancing edge of the lesion. Diseased areas originating at a leaf tip often are V-shaped. As the injured area dies, the leaflet frequently curls downward. The fungus can invade entire leaflets and attack petioles, causing wilting and death.

Since the disease mainly affects leaves, grazing or cutting the clover removes diseased foliage and reduces danger to new growth. Experimental data indicate that resistance to Curvularia leaf spot can be readily obtained (*71*).

Sooty Blotch

Sooty blotch, caused by the fungus *Cymadothea trifolii* (Pers. ex Fr.) Wolf, is most prevalent during cool seasons. The disease generally occurs during late summer and fall in the Northern States and during the winter and early spring in the South.

The granular, black blotches are usually angular and are most conspicuous on the underside of leaves. Later, when overwintering fruiting bodies of the fungus develop, the blotches appear raised, black, and warty. Infected leaves turn yellow and wither prematurely (*60*).

The disease is not so destructive on white clover as it is on some other clover species. Grazing or cutting the foliage removes the fungus inoculum and reduces subsequent infection.

Rust

Rust, caused by *Uromyces trifolii* var. *trifolii-repentis* (Liro) Arth., attacks white clover petioles and leaflets, resulting in premature shriveling and death. The most conspicuous symptom occurs during the brown rust stage, usually in late summer and fall.

Rust pustules are generally deep reddish brown. They occur principally on the underside of leaflets and along petioles. If pustules are numerous and well developed, the upper surface of infected leaflets turns yellow or red. Infected leaves often become distorted. Sometimes during wet weather in the fall or early spring, small, swollen, yellow clusters of aecia, or tiny cuplike structures, develop on leaf petioles and the veins of leaflets. This kind of infection markedly distorts leaves and petioles (*60*).

Most of the improved varieties of white clover are not damaged so severely by rust as their predecessors. Grazing and clipping stands help to reduce injury. Stands left for seed can be severely damaged by rust infection.

Viruses

The viruses commonly attacking white clover are widespread and prevalent. Some of them also attack other related and unrelated hosts, such as alfalfa, peas, beans, potatoes, strawberries, and some weeds. The most common viruses, like alfalfa mosaic, bean yellow mosaic, and white clover mosaic (*78*, *92*), are spread by grazing, mowing, and insect vectors, principally species of aphids. The virus causing a condition known as phyllody is spread only by certain species of leafhoppers. Absence of virus symptoms does not mean a plant has recovered from virus infection. Symptoms merely become so inconspicuous that they are temporarily undiscernible. Baxter and McGlohon (*13*) reported a method of freeing some clones of one virus. Their method may be valuable to plant breeders for eliminating the virus from parental clones to be used for seed production.

Viruses causing mosaic symptoms generally induce mild to severe mottling in leaves (fig. 9). Sometimes the veins become light colored and conspicuous. Usually light-green to yellowish blotches develop as patches between the veins. In some cases, leaves curl downward or appear ruffled. Severely diseased plants are frequently stunted.

Phyllody is induced by a strain or strains of aster yellows virus. The same or closely related strains of the virus induce symptoms in strawberry known as green petal disease (*48*). To date, infection has been reported only in California, Oregon, and Maine. Phyllody symptoms are characterized by transformation of floral organs into dwarfed leaves. The flower head may be comprised entirely of abnormally elongated florets or of leaves in various stages of normal or abnormal development (*57*).

Virus infection generally stunts plants, reducing yield and seed production up to 50 percent (*76*, *77*). Diseased plants are usually weakened. This predisposes them to killing by pathogenic fungi and adverse environmental conditions. Virus infection increases in a clover stand from season to season, often reaching 50 to 75 percent of the plants in 3 years. Longevity of stands may be seriously reduced by virus infection.

Virus infection is difficult to control, because once a plant becomes infected it remains diseased until death. At present, no virus-resistant white clover plants have been found; however, some lines tolerate virus infection better than others. Fortunately the viruses of white clover are not seedborne. If possible, fields should not be sown adjacent to other leguminous crops. When a crop is being grown for seed, insecticides may be judiciously applied to reduce prevalence of insect vectors.

Stolon and Root Rots

Stolon and root rots are sometimes not so conspicuous as foliar diseases, but they are frequently more destructive and responsible for reduced yields and stand persistence. In the North, yield of white clover is usually satisfactory the first harvest season, but it decreases substantially in the second and third seasons (*72*). The yield decline is correlated with stand thinning during the second and subsequent growing seasons. In the South, white clover failure occurs mostly during the summer, and it is attributed largely to disease attacks (*3*). Stolon damage occurs from May until September and is closely associated with high summer temperatures (*49*, *50*, *83*).

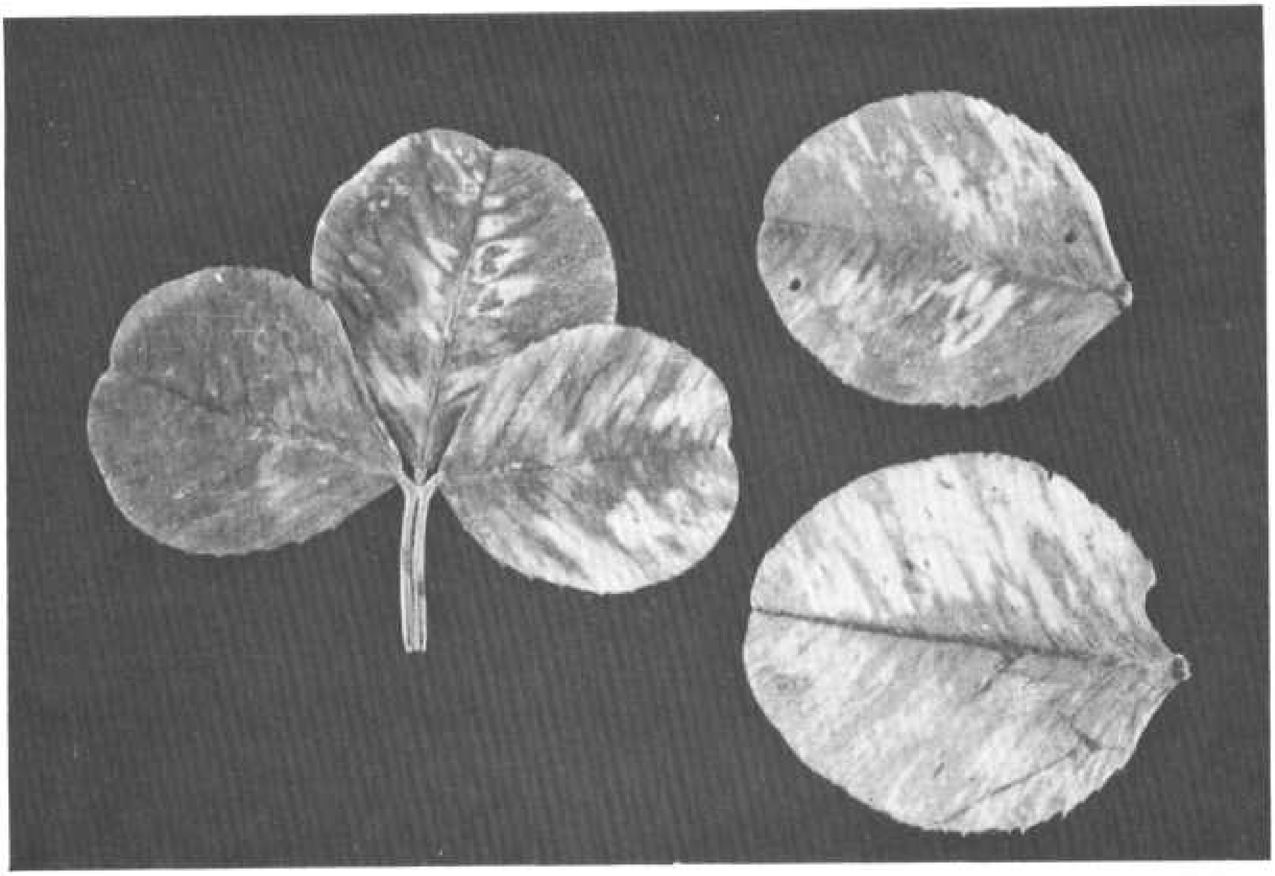

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FIGURE 9.—Yellow streaking and mottling in leaves of Ladino white clover caused by virus infection. Viruses are transmitted in plant juice by insects and mechanical injury.

Stolon and root rots are dependent on the interaction of several agents, including fungi, nematodes, insects, environmental conditions, and age of tissue. Among the most prevalent fungi associated with diseased stolons and roots are species of *Fusarium*, *Rhizoctonia*, *Colletotrichum*, *Leptodiscus*, and *Curvularia*. Sometimes the charcoal rot fungus *Macrophomina phaseoli* (Maubl.) Ashby damages fields in the South (*59*).

Disease symptoms on roots usually consist of brown to black sunken lesions that may be discrete or they may coalesce and girdle or discolor the entire root. Lesions are sometimes the result of insect feeding (*Sitona* spp.). Fungi enter tissues through the wounds and destroy the root (*55, 72*).

Fungi invading roots often penetrate into stolons causing their death. The same fungi that invade roots can enter stolons through wounds induced by grazing animals, farm machinery, and exposure to the sun. Stolon internodes die and wither, leaving a mass of dead stolons and bare soil where abundant foliage formerly occurred.

Although most stolon and root injury occurs during the summer, damage from the fungus *Sclerotinia trifoliorum* Eriks. sometimes occurs during the winter or under heavy and prolonged snow cover (fig. 10). Diseased plants generally are in patches, and dead leaves and petioles mat in a papery crust of tan to white dead plant tissue. Diseased stolons are often flaccid and brown. Later, hard black sclerotia form, which may adhere to the surface of or be imbedded in stolons. The fungus generally becomes inactive when the temperature reaches 80° F. (*74*).

Because of the numerous agents involved in stolon and root diseases, no effective disease-control measures are presently available. Damage can be lessened somewhat by growing adapted varieties and following recommended cultural practices.

Nematodes

Nematodes feed on and damage roots of white clover in many parts of the United States. Most widespread damage occurs in the South, princi-

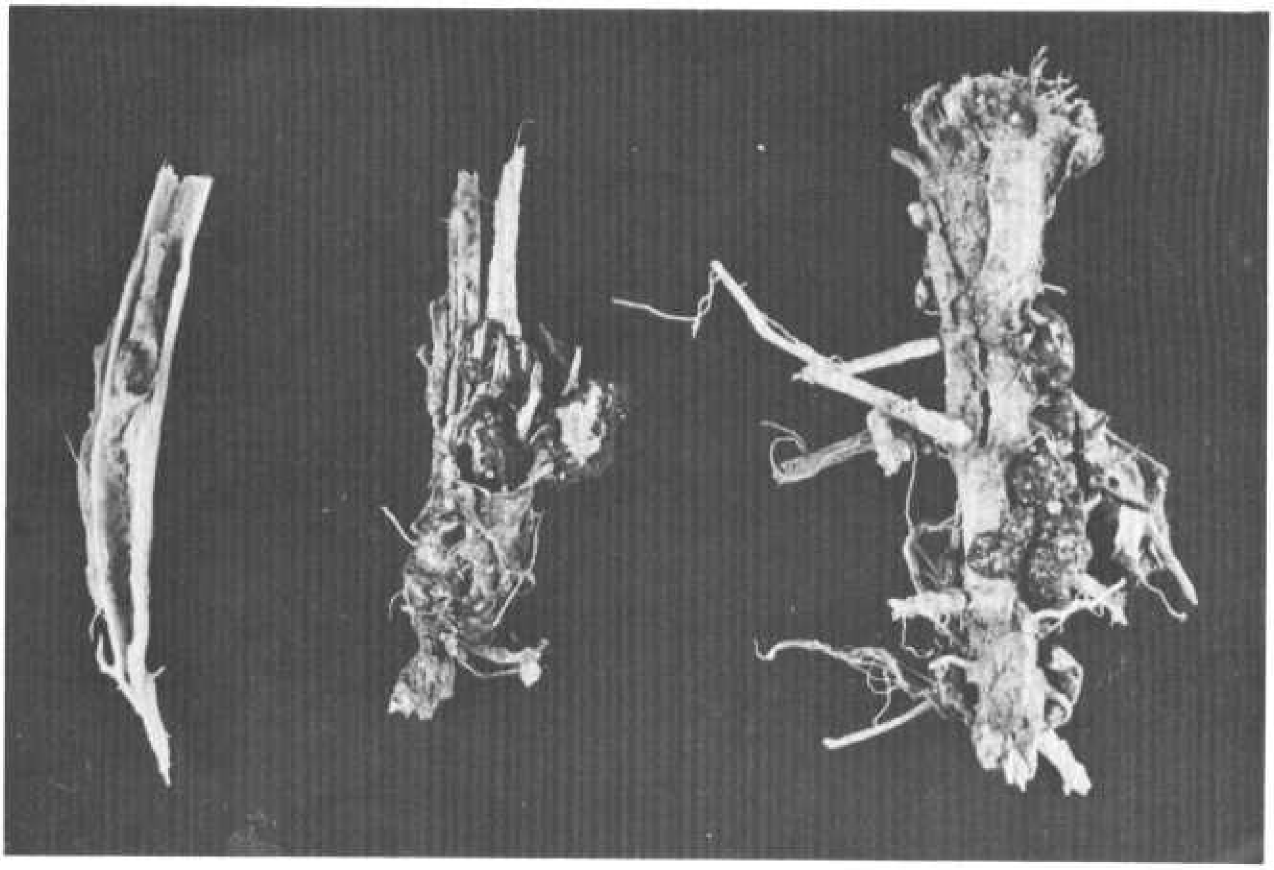

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FIGURE 10.—Sclerotia (resting or carryover stage) of fungus *Sclerotinia trifoliorum* causing crown and stem rot disease of white clover. They germinate and spores infect plants in fall. Plants are killed during winter and early spring.

pally from infestations of root-knot nematodes (*Meloidogyne* spp.) (*12*). Localized damage often results from feeding by other kinds of nematodes, such as sting, meadow, and clover cyst nematodes. Surveys suggest that many kinds of nematodes probably feed on roots of white clover, but the amount of damage incited by each has not yet been adequately assessed (*84*).

Symptoms of nematode injury include plant stunting, unthrifty growth, and untimely death of plants during hot, dry periods in the summer. Root-knot and cyst nematode infestations induce swellings or gall formation on roots. Nematode cysts and galls often resemble nodules of *Rhizobium* spp. Meadow and sting nematode injury is frequently indicated by shortened and thickened roots that may be uniformly discolored brown or contain discrete brown lesions. Not only does nematode feeding weaken plants but soilborne fungi may invade roots through nematode-induced wounds, causing additional injury.

Crop rotation is not always effective for nematode control, since many species attack unrelated hosts. Cyst nematodes can survive for long periods in soil in the absence of a preferred host. Fumigation with nematocides is presently too expensive and impractical for white clover. Selecting white clover plants resistant to nematodes appears promising (*11*).

INSECT PESTS[4]

Many species of insects attack and damage white clover. They may prevent or reduce plant growth, destroy plant tissue, or damage the seed. Some of them are general feeders on many species of plants, whereas others largely restrict their feeding to a few species of legumes. A few of

[4] Prepared by B. A. App, entomologist, Entomology Research Division.

these pests attack almost any part of the plant above ground, but others attack the roots, and still others confine their feeding to the flowers or seed. The successful clover grower must learn to recognize and control destructive insect pests. A brief description of the more important species follows.

Grasshoppers

Many species of grasshoppers attack many kinds of plants and may sometimes damage white clover by feeding on the leaves and stems and often on the flowers and seed.

Clover Leaf Weevil

Larvae of the clover leaf weevil (*Hypera punctata* (F.)) often cause considerable loss of white clover leaves early in the spring. When full grown, these larvae are about one-half inch long and green, with a white or pinkish line down the center of the back. The adult is about one-fourth inch long and one-eighth inch wide. It is covered with brown, yellow, and gray scales, which give it a mottled appearance. Fortunately the larvae are attacked by a fungus disease if humidity is sufficiently high to favor spore germination and infection. Control methods are not usually needed.

Potato Leafhopper

Feeding by the potato leafhopper (*Empoasca fabae* (Harris)) causes a reddening bronzing and browning of the clover leaves and may stunt the growth. The adult leafhoppers are pale-green wedge-shaped insects about one-eighth inch long. Eggs are deposited within the stems and larger leaf veins. The eggs hatch into small whitish nymphs, which later become pale green. Several generations are produced each year. This insect overwinters only in the extreme Southern United States and migrates north each season. When plant growth is retarded by unfavorable weather, leafhopper damage may become severe.

Meadow Spittlebug

Almost all damage by the meadow spittlebug (*Philaenus spumarius* (L.)) is done by the nymphs sucking the plant juices. The eggs are laid in the fall and hatch the following spring into nymphs, which are protected by a mass of spittle. Their feeding stunts the clover plants and often causes a rosetting of the terminal growth. From one to several nymphs may inhabit a single spittle mass. There is only one generation a year.

Garden Fleahopper

The garden fleahopper (*Halticus bracteatus* (Say)) sucks plant juices and causes small discolored areas on the clover leaves, which give the plant a mottled appearance. Heavy feeding may result in death of the leaves.

Spider Mites

Spider mites of several species often damage white clover. They feed on the underside of leaves and spin delicate webs. Infested leaves have yellow blotches, which range in size from small specks to large areas. In the Western States, particularly in areas under irrigation, these pests are very serious when the crop is grown for seed.

Clover Root Curculio

The clover root curculio (*Sitona hispidula* (F.)) is probably the most economically important insect that infests the roots of white clover. The adults are small brownish-gray snout beetles about three-sixteenths inch long. They cut small circular notches in the leaves. The most significant damage is caused by the larvae gouging the roots. Larvae are about three-sixteenths inch long with yellowish-brown heads. There is only one generation a year. The eggs are laid in the fall, and the young larvae overwinter in the soil.

Green June Beetle

Larvae of the green June beetle (*Cotinis nitida* (L.)) damage white clover by uprooting the plants as they burrow through the soil feeding on dead organic matter. They measure nearly 2 inches long when full grown. Generally they are glossy white and have a rather small brown head. A peculiarity of the larvae is that, although they have legs, they travel on their backs by means of stiff bristles. The adult beetles are velvety green with margins of orange yellow and are about three-fourths inch long. There is only one generation a year. Adults are active from June to September and lay eggs in August and September. In 10 to 15 days the eggs hatch into grubs, which pass the winter in the soil and become full grown by the following May.

Lesser Clover Leaf Weevil

Both adults and larvae of the lesser clover leaf weevil (*Hypera nigrirostris* (F.)) feed on clover, but most of the damage is done by the larvae. They feed in the axil of the leaves, terminal buds, and developing heads. In severe infestations many terminal and side buds may be destroyed. The adults are small snout beetles about one-eighth inch long with iridescent, greenish, scalelike hairs. The larvae are legless, grayish grubs about three-sixteenths inch long with brownish-black heads. There is a single generation annually. The adults overwinter in trash and debris on the ground. Eggs are laid in early spring, and most of the larvae are full grown by mid-June.

Clover Head Weevil

The clover head weevil (*Hypera meles* (F.)) is closely related to the lesser clover leaf weevil. The larvae usually occur in the clover heads, where they feed on the florets and developing seed. Their feeding causes small misshapen flower heads and reduced seed production. These two species are largely responsible for the poor seed yields of white clover in the South. The adult is brown, about three-sixteenths inch long, with three longitudinal whitish stripes. The full-grown larva is legless, about five-sixteenths inch long, with a rusty-brown head. Generally it is pearly white or grayish with faint-brown or bluish longitudinal stripes. The insect overwinters as an adult and lays its eggs during the spring in slits in the leaf petioles or stems. Larvae become full grown sometime in midsummer. There is a single generation a year, but some evidence of at least a partial second generation has been observed.

Clover Seed Weevil

The clover seed weevil (*Miccotrogus picirostris* (F.)) was first noted in the United States in the State of Washington in 1929, and has since been found over much of the clover-growing area. Its preferred hosts are white and alsike clovers. The adults are small gray weevils about one-tenth inch long. They feed at the base of the calyx and lay their eggs in punctures on the calyx. The larvae feed on the developing seeds, and each larva may destroy from two to four seeds. When full grown, the larvae are small, plump, white grubs about one-eighth inch long with light-brown heads and no legs. Winter is passed as an adult. Egg laying occurs in June and July. There is one full generation and possibly a partial second generation each year.

Ladino Clover Seed Midge

The Ladino clover seed midge (*Dasineura gentneri* Pritchard) is a pest of white and alsike clovers in Oregon and Washington. The larvae overwinter in tiny cocoons on or slightly below the soil surface. They are white, changing to yellowish pink as they mature. The larvae feed on the flower parts and prevent seed formation. Adults emerge in the spring and lay eggs in the immature flowers. They are small mosquitolike flies. Several generations a year are produced.

Other Damaging Species

Several other insects may sometimes damage white clover. Lygus bugs (*Lygus* spp.) and other plant bugs attack the buds, blossoms, and seeds and may lower seed yields. The clover aphid (*Nearctaphis bakeri* (Cowen)) may sometimes be abundant. The green cloverworm (*Plathypena scabra* (F.)) is often found on the foliage. Cutworms may cause some injury at times. White clover, particularly that grown in small plots, is occasionally damaged by other insects not normally considered pests of this crop. Some of these are the lesser cornstalk borer (*Elasmopalpus lignosellus* (Zeller)), the alfalfa weevil (*Hypera postica* (Gyllenhal)), blister beetles (*Epicauta* spp.), and the fall armyworm (*Spodoptera frugiperda* (J. E. Smith)).

Control

Many of the more serious pests of white clover can be controlled with insecticides. Recommendations are constantly being improved, and county agricultural agents and State agricultural experiment stations should be consulted for the latest recommendations for their areas.

REQUIREMENTS FOR GROWTH AND SOIL ADAPTATION

White clover grows in every State. Thick productive stands depend on the use of adapted varieties, proper amounts and kinds of fertilizers and limestone, and good grazing and clipping management. Successful inoculation, favorable weather, and correct planting with the associated grass on an adapted soil also are essential (*1*).

Soil Adaptation

White clover is best adapted to soils ranging from clays to silty loams. It will grow in lowlying sandy soils that have a high water table, but it is not recommended for soils that are droughty, swampy, or low in fertility. It is not tolerant of saline soils nor does it thrive on high alkaline soils. Highly alkaline soils have been made suitable for the growth of white clover by applications of relatively large amounts of superphosphate. Annual applications are generally more effective than correspondingly heavier applications once every second or third year. The high phosphorus requirement for growth of white clover on these soils is probably explained by the high phosphorus fixing capacity of the soils and the crop's requirement for a continuous, readily available source of phosphorus.

Fertilizers and Limestone

Available supplies of phosphorus, potassium, and calcium are essential to stand establishment and good growth (*30*, *47*). Phosphorus and potassium are supplied in various formulations of commercial fertilizers. Calcium is supplied as agricultural ground limestone. On certain soils, particularly those of a sandy texture, magnesium and sulfur may be deficient. The use of dolomitic limestone will supply both calcium and the magnesium. The use of superphosphate as the source of phosphorus will supply the sulfur. In a few areas, some of the minor elements must be applied for the highest yields of forage and seed. Of the major minerals, the amounts needed will generally range from 300 to 600 pounds of 20-percent superphosphate and from 60 to 250 pounds of muriate of potash per acre or their equivalents.

In comparison with other clover species, white clover needs more potassium (*22*). It frequently responds to greater amounts of potassium than are customarily applied (*29*, *30*). Finely ground limestone at rates of 1 to 4 tons per acre is generally applied when needed.

The county agent, Soil Conservation Service technician, or State agricultural experiment station should be consulted on kinds of minerals and amounts needed, since these vary widely depending on the natural fertility of the soil and previous fertilizer treatments. These agencies normally base their recommendations upon the results of soil tests.

Inoculation

Although white clover will grow in slightly to medium acid soils, higher yields, longer lived stands, and better inoculation are obtained if the pH is from 6 to 7. The symbiotic relationship of nitrogen-fixing bacteria and the clover is most effective at a pH near 6.5 and enables the clover plants to utilize atmospheric nitrogen. Well-inoculated plants are not benefited by the application of nitrogenous fertilizers. Normally the application of nitrogen fertilizer complicates management of a clover-grass pasture and does not cause economical increased production of forage (*94*, *108*).

In the North, where white clover has recently grown, bacteria generally are present in the soil to bring about good inoculation. However, reduced production is so great in the absence of good inoculation and the cost of inoculating so small that it is wise to inoculate whenever a new seeding is made. Also, there may be another advantage in inoculating the seed regardless of the presence of bacteria in the soil. Laboratories of educational and research agencies and most commercial companies manufacturing cultures are continually working to isolate and culture the most efficient strains of bacteria. These superior cultures increase the amount of nitrogen fixed. In the South, it is even more important to practice inoculation at every seeding, because high soil temperatures over several months may seriously reduce the number of bacteria at or near the soil surface.

Climate

White clover grows best during cool, moist weather. Good growth occurs at 50° to 85° F. (*15*, *88*, *96*). White clover is seldom found above timberline in the western mountains, and the authors believe that the low summer temperatures are the limiting factors rather than low winter temperatures. On the other hand, high summer temperatures with drought conditions or with high humidity are unfavorable for persistence of stands. Interesting temperature relations occur in both Hawaii and Alaska. In Hawaii, white clover does not grow under tropical conditions at low altitudes, but on adjacent mountains at elevations above 3,000 feet it thrives under the more temperate conditions (*27*). In Alaska, it grows near Anchorage, Palmer, and Fairbanks at low winter temperatures associated with long periods of winter dormancy.

A readily available supply of moisture in the top 6 inches of soil is essential for good growth of white clover. When grown under irrigation, frequent applications of water are needed, but the amount applied at any one time may be less than is used with deeper rooted crops. Wilting of white clover is not a sure sign of deficient soil moisture. In the hot inland valleys of the Western States, white clover frequently wilts in the afternoon when the temperature is high and the humidity is low even though the soil is moist.

PRODUCTION PRACTICES

Management in the North

Practically all the white clover seeded for pasture, hay, or cover in the Northern and Western States is the Ladino variety or others of the large type. However, many pastures that are unimproved or that are used for night pasture with close continuous grazing are of Common White. Reference here will be to Ladino and other improved varieties of the large type unless otherwise stated. This does not mean that Common White is without importance, for without this clover most unimproved pastures would be nothing but exercise areas for animals. Fertilizer and lime requirements are somewhat less for Common White than for the varieties of the larger type, since it is less productive. Seeding rates and mixtures are approximately the same.

Seedbed Preparation and Seeding

Lime and fertilizers may be applied before seedbed preparation or, better yet, worked into the soil surface of the seedbed. The seedbed should be very firm, smooth, and free of weeds. This may be accomplished by the use of a corrugated roller following the usual plowing, disking, and harrowing operations. A loose, cloddy seedbed and a deficiency of required minerals are probably the most frequent reasons for failure to establish stands.

The seed may be broadcast on the surface, drilled, or planted by a combination corrugated roller-seeder. Since white clover seeds are very small, they must be planted at or near the soil surface not more than one-eighth inch deep, preferably less on most soils. Depending on the mixture used or if seeded alone, the rate of seeding varies from one-half to 5 pounds per acre, respectively. The seed should be inoculated with a white clover culture before planting by following instructions given on the container.

Mixtures

Except for swine and poultry pastures and seed crops, which are seeded alone, most white clover is seeded with one or more grasses—orchard, timothy, brome, tall fescue—and the legumes red clover and alfalfa. Kentucky bluegrass should be avoided where it is highly competitive with white clover. Strong competition makes maintenance of clover stands difficult. Of first importance in the establishment and particularly the maintenance of good stands of clover is a light rate of seeding for the grasses. This is somewhat contrary to former practice.

Recent research has indicated that the seedling taproot of white clover does not persist much longer than a year and that elaborated metabolites and absorbed minerals are mainly translocated to newly developing meristematic tissue, that is, toward the stolon tips and nodal roots. The authors believe that the older roots and stolons become senescent, fail to grow, and are subject to attack by many pests, particularly viruses and soilborne fungi, which lead to their deterioration and death. The new developing plants must compete with the older established plants in the association, and the survival of a stand may be jeopardized by even one unfavorable environmental factor. This competition is suggested as the principal reason for early stand losses. Additional research to determine the effect of grass populations on white clover development and survival is needed. Until more is known, thick stands of grass should be avoided (*63*).

Time of Seeding

Spring seeding may be made alone or with a companion grain crop and should be done early. Late-spring seedings are less successful. Frequently the companion grain is seeded at one-half the normal rate to reduce its competition for light, moisture, and nutrients. If the legume-grass seeding is of first importance, the grain crop may be grazed, starting when it is approximately 12 inches high, or cut for hay or silage when the heads are in the soft dough stage. It is not advisable to practice close grazing or let animals trample the young seedlings when the soil is wet. The young clover may be grazed when growth permits and the weeds clipped or sprayed with a specific herbicide for control. If the grain crop is harvested for grain, the stubble should be clipped and all straw removed as soon as possible after harvest.

July and August seedings are successful, particularly under humid, cool conditions. They have the advantage of coming at a time when there is less competition with other farm operations and more time can be spent preparing a good seedbed. The seeding must be made sufficiently early for the plants to become well established before the advent of winter. Small plants are readily heaved out of the soil by freezing and thawing.

Defoliation Practices

One of the excellent characteristics of white clover is its remarkable ability to make rapid regrowth after defoliation (*62*). This characteristic enables the plants to tolerate the competition of associated plants. Depending on the degree of favorable environmental factors and the associated plants, the forage may be either grazed or cut at intervals of 15 to 30 days during the spring and summer.

White clover also has been used in green feeding practices. Unfortunately the heavy machinery necessary for this method of utilization severely injures the plants, providing an entrance for diseases. This leads to early loss of stands.

Where winter conditions are severe, white clover should not be closely grazed or frequently cut in the fall, as such a practice favors winter injury (*101*). Many successful growers follow the practice of topdressing white clover with barnyard manure soon after the soil surface becomes frozen in late fall.

When white clover is grown in association with other legumes or grasses for hay or silage, it is highly desirable to harvest the crop early even though some yield is sacrificed. Delayed harvesting favors the development of leaf diseases, reduces light reaching the clover, and consequently is detrimental to rapid recovery and growth of the clover. Regrowth of clover is dependent on the amount of functional leaf surface that is left after grazing or cutting. For this reason, the forage should not be grazed or cut shorter than 2 inches (*29*). Rotational grazing is more favorable for clover than continuous grazing, for under continuous grazing some areas are grazed too closely and forage is not adequately utilized from other areas. White clover has been successfully used under daily ration grazing, although care should be exercised to avoid excessive trampling on the fleshy stolons.

Renovation of Pastures

If an established stand of white clover is lost, it may be reestablished in either of two ways. If there is a thick stand of grass, it must be killed either by cultivation or by the use of selective herbicides. Depending on the kind of surviving grass and the weather, it may be necessary to plow or disk and harrow several times. After the grass is killed, it is necessary to prepare a very firm seedbed as previously described.

Where the clover has set good quantities of seed during the years before the loss of the stand and where the associated grass has not formed a thick turf, volunteer clover stands can be established under favorable climatic conditions by continuous close cutting or grazing of the grass, or by opening the turf by disking. Until the young seedlings are established, the intensity of defoliation should be modified to favor their survival. This method has been very successful when timothy is the associated grass.

If the seeding is to be primarily used for grazing, alfalfa is not a good companion legume in the mixture, as it will not survive under the frequent defoliation that produces maximum yields of the clover.

Ratio of Clover to Grasses

Maintaining a desirable ratio of clover to grass is both challenging and rewarding (*107*). A sward of 50- to 70-percent clover is considered good by beef cattle producers and dairymen. In general, dairymen prefer higher percentages of clover. Most poultry and swine producers prefer all or almost all clover. The ratio will vary with seasons and years, since all changes in growing conditions affect the ratio. Management practices can be followed to prevent an excessive shift as a result of climatic conditions.

Management in the South

White clover is used primarily as a pasture crop throughout the southern region. The varieties used range from predominantly Louisiana White or other improved varieties that produce good seed crops in the Gulf Coast area to predominantly Ladino near the northern boundary of the region. In general, the varieties that flower profusely and consequently produce considerable seed are used in areas and on soils where maintenance of the clover stand depends on volunteer plants (*18*, *21*). Ladino is used where the clover normally persists more than one winter. In Louisiana and adjoining States a considerable acreage is managed for both seed production and grazing. A small acreage in Texas, Louisiana, and Arkansas is used in rotation with rice. Information concerning these and other special uses can be obtained from local agricultural agencies. This discussion will be limited to its use in clover-grass pastures.

Seedbed Preparation and Planting

Methods of preparing and the characteristics of the seedbed are the same as those described for the North. Early and thorough preparation that results in accumulation of soil moisture and the formation of a firm seedbed prior to planting favors success in establishing stands. Most States recommend a seeding rate of 2 to 3 pounds per acre and double this amount if seeded alone for poultry, swine, or seed production. Seed should be inoculated before planting. The seed may be broadcast or drilled. The equipment used for planting should assure shallow coverage—not more than one-eighth inch, preferably less on most soils.

The rate and method of planting the grass should assure that space is available for growth of the clover (fig. 11). Drilling grass in adequately spaced rows is one method of providing sufficient space for the clover.

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FIGURE 11.—Good stand of white clover has persisted in this pasture for 3 years. Planting tall fescue in rows 18 inches apart helped provide space for clover. (Courtesy Clemson University.)

Associated Grasses

White clover should be seeded with a grass to make its greatest contribution to supplying forage for livestock. The grasses most frequently used in the South are orchard, tall fescue, Kentucky blue, dallis, and bermuda. Other grasses used are varieties of bahia, pangola, johnson, and carpet. The thick turf by Pensacola and Paraguay varieties of bahia, bermuda, carpet, and St. Augustine grasses is not compatible with white clover. On the other hand, the open growth of dallis and common bahia grasses permits white clover to thrive. Since these grasses are aggressive, under conditions favorable to the grass and unfavorable to the clover, the association may shift to all grass.

Intelligent management is essential to maintain a desirable ratio of clover to grass. Periodic renovation or, better yet, the practice of rotation with a cultivated crop usually results in higher production of forage and a better ratio of clover to grass. Also the inclusion of a nonclover crop for 1 or more years after several years of clover should reduce damage from clover diseases and aid in the control of troublesome weeds.

Time of Seeding

The optimum planting date varies with the location, soil type, and soil moisture. Late-summer and early-fall seedings are generally preferred, since rapid root development occurs during cool, moist periods and thus favors survival the following summer. In areas where freezes occur in November and particularly on soils that heave badly, seedings should be made the last part of August or early September. Where the winter is milder and heaving is less important, seedings made as late as December may be successful. Spring seedings are hazardous; however, on moist soil with a low weed population, spring seedings often are successfully made.

Utilization

White clover may be grazed when the sward reaches a height of 3 to 4 inches. If temperature and moisture are favorable, this will occur 2 to 4 months after seeding. Light grazing at first is recommended to permit good establishment and the development of stolons. Thereafter, the grazing may be more intense.

The height of the associated grasses must be kept relatively short for the best development of the clover. If growth is more rapid than can be utilized by grazing, the excess forage can be made into either hay or silage. An occasional clipping of the pasture to make the growth more uniform and to control weeds is desirable.

Animal droppings should be scattered to obtain uniform growth of the pasture, except where a seed supply for fall volunteering is needed. The undisturbed droppings make seed islands, which are valuable for reseeding.

Forage should be utilized soon after it is produced. This may be done by rotational grazing or by controlled continuous grazing during the growing season. If continuous grazing is used, stocking should be controlled so that the height of forage is maintained at 2 to 6 inches. On heavy soils, grazing during wet periods should be avoided if practical. Accumulating large amounts of forage to be used during hot, dry periods or during cold weather is hazardous. Clover leaves that touch the ground because of wilting or other causes are soon lost. Leaves on the ground favor the development of diseases that may destroy the stand. Undergrazing more often than overgrazing properly fertilized pastures results in the loss of clover.

Fall Management

Fall management may profoundly affect the growth of white clover the following year. Stolons formed in the fall often become strong growth centers by the next spring. Growth at low temperatures is characterized by short internodes, profuse branching, and extensive root development (*96*). These characteristics contribute to forage production and persistence of stands the following spring and summer. To favor high production the following year, the management practices employed in the fall should provide the conditions necessary for growth and rooting of new stolons.

Practices Affecting Botanical Composition of Clover-Grass Association

The following list is a summary of practices or conditions that affect the botanical composition of a clover-grass association.

Initial population:

(1) *Seeding rates.*—The number of viable seed per acre of each crop planted obviously determines the initial balance. Avoid high seeding rates of grass, as the resulting stand will crowd out the clover.

(2) *Time of seeding.*—On clay soils, delaying the fall seeding date tends to increase the loss of clover seedlings from heaving.

(3) *Nitrogen fertilizer.*—Applying nitrogen fertilizer favors the establishment of the grass seedlings and retards the clover.

(4) *Covering seed.*—Clover seed should barely be covered. Grass seed will push through from greater depths.

(5) *Seedbed.*—It must be firm. This can be accomplished by rolling before and after seeding.

Practices tending to shift plant population toward grass:

(1) Applications of nitrogen fertilizer.

(2) Undergrazing, thus permitting grass to grow above the clover.

(3) Lack of lime, phosphorus, and potassium.

(4) Permitting grass to mature seed.

Practices tending to shift plant population toward clover:

(1) Adequate utilization so that grass does not grow tall. It may be necessary to harvest forage for hay or silage to prevent excessive accumulation of growth.

(2) Withholding nitrogen fertilizers.

(3) Adequate applications of lime, phosphorus, and potassium.

(4) Mowing to control weeds and to remove islands of undergrazed tall grass.

Practices aiding in establishment of volunteer clover stands on existing summer perennial grasses:

(1) Removal in fall of accumulated grass by close grazing, harvesting, disking, or burning.

(2) Fall application of lime, phosphorus, and potassium.

Seed Production

Seed production of white clover often is outside the area of utilization, since the environment favoring profuse flowering and seed harvesting may differ considerably from that of the area where the variety is used for forage. Naturalized varieties and ecotypes usually flower profusely in areas where the photoperiod is as long as or longer than that of the place of origin (*98*, *102*). Sparse-flowering varieties require longer photoperiods for high seed yields.

The practice of producing seed of a variety outside its area of adaptation or use frequently results in a genetic shift (*34*). This is particularly important in a synthetic variety composed of clones having different requirements for flowering (*98*).

An abundance of bees for cross-pollination and dry, warm weather are necessary for high seed yields. Bees work white clover flowers for both nectar and pollen. The honey bee is by far the most important species for cross-pollination (*23*, *64*). The honey bee population can be controlled readily by moving colonies in and out of seed fields. Prolonged cloudy, rainy weather reduces flowering and retards bee visits. For this reason, most of the white clover seed is produced in the Western States, where clear, bright weather prevails. Such weather favors flowering and the development of large plump seed, facilitates harvesting, and reduces harvesting losses (*86*).

Seed yields may vary from 30 to 200 pounds per acre under humid eastern conditions, whereas in the West, yields range from 150 to more than 600 pounds per acre depending on the variety and environmental conditions.

There is some evidence that Ladino and other varieties of the large type produce fewer flowers and less nectar per floret than the intermediate- or small-type varieties. This makes them less attractive to the bees and adversely affects seed production (*23*).

The production of large yields of high-quality seed is specialty agriculture. Important factors are control of destructive insects, cautious use of insecticides to protect pollinating insects, and wise use of selective herbicides and defoliants (fig. 12). Timeliness is a prime necessity in seed production.

Since white clover is indeterminate in flowering, ripe seed and florets in full bloom may be seen on the same plant. The seed crop should be harvested when most seed heads are a light brown. This condition usually occurs from 25 to 30 days after full bloom. In western areas under irrigation, where weeds and destructive insects have been controlled on the first crop, a second seed crop may be produced and both crops harvested in one operation. The seed crop is cut with a mower and is cured either in the swath or in small windrows and is picked up out of the swath or windrow with combines equipped with pickup attachments. Careful operation of the combine, both in the rate of forward speed and in the adjustment of the cylinder speed and of the concaves and screens, is important for good harvesting with the least loss. During showery weather, curing in the swath facilitates combining, whereas during clear, warm weather, windrowing reduces harvesting losses.

The cut crop should be handled as few times as

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FIGURE 12.—Seed field of Ladino clover in Northwest, showing profuse flowering and growth with irrigation. Obtaining good seed yields includes wise use of irrigation water, pollinating insects, fertilizers, insecticides, selective herbicides, defoliants, and seed-harvesting equipment.

necessary, since each handling causes shattering losses. Under humid conditions, artificial drying or spreading the seed thinly under cover for complete drying improves the seed quality. If the latter method is followed, the seed should be turned every few days until dry. Rough cleaning both before and after drying increases the rate of drying and improves the quality.

Defoliation of the seed crop in humid States has not proved to be a dependable practice, because rainy, damp weather may occur after defoliation and before the crop is combined. Under the dry, bright conditions of the West, defoliation is successfully followed. Suction harvesters are widely used in the West both on defoliated fields and where the plants have been windrowed.

RESPONSES OF WHITE CLOVER TO CLIMATIC FACTORS

Environmental factors profoundly affect the chemical composition and growth of white clover. HCN (hydrocyanic acid) content was found to decrease with increases in both latitude and altitude (*37–40*). In one experiment, plants were grown in controlled-environment chambers under different temperatures. The percent of maltose was highest at low temperature (50° F.) and decreased with increasing temperature; at 86°, maltose was present only in trace amounts. In contrast, sucrose concentrations were as high in plants at high temperatures as in plants at 50° (*16*).

Wide variation exists in growth response among different genotypes under various temperatures. One clone failed to grow at 50° F., whereas others made considerable growth. This same clone persisted under extremely high field temperatures, whereas others died. Apparently white clover makes greater growth between 60° and 75°. Stolon branching is greater at lower temperatures and high light intensity (*15*). In the field, the branches are important in the rapid spring production of forage.

At high temperatures, white clover rapidly disappears if grown in association with a thick stand of grass. Although it will persist longer at lower temperatures, little growth is made. In plant-growth chambers, approximately the same amount of dry matter per unit of leaf area was produced under light conditions of 600, 900, and 2,000 foot-candles. The higher light intensity increased leaf production and plant weight but decreased the functional period of the leaf (*15*). It is apparent that profuse flowering and seed setting are directly associated with increases in light intensity and day length. High light intensity is probably the principal reason for the high yields and large seed produced in the Western States.

Most literature references on white clover indicate that winter hardiness is important in adaptation under low winter temperatures. Although it is true that field differences in survival are evident in the spring, the reasons for these differences are usually obscure (*95*). The authors believe that the interactions among physiological, pathological, agronomic, and climatic factors causing stand losses in the spring after severe winters have a greater effect on survival than the direct effect of low temperatures. Predisposing factors in the fall show their effects in early spring. Ladino, considered by some to lack winter hardiness, has survived under extreme temperatures ranging from −40° to 40° F. during the winter, even with little snow cover.

NUTRITIVE VALUE AND CHEMICAL COMPOSITION

White clover is probably the most nutritious legume for livestock and poultry, either in the green state or as hay (*73, 85, 106*). Only the leaves are grazed or harvested, and they are the most nutritious part of the plant. For this reason, yields are relatively low. Under close grazing some animals and poultry feed on the stolons. This is harmful to the stand and reduces the rapid regrowth of the plants. White clover is a quality-concentrated feed if utilized before the leaves have aged. It is very palatable, although cattle and sheep grazing on practically pure stands of lush white clover have been observed searching for and eating coarse, fibrous plants or plant parts.

Since nutritive value depends on both chemical composition and digestibility, numerous analyses and digestion tests of white clover have been made. The chemical composition of the leaves varies depending on their age, cultural practices, and environmental conditions; however, there is less variability when compared with other forages whose stems are included (*110*). Samples have assayed over 30 percent crude protein.

Compared with other forages, white clover rates high in amino acids. Loper et al. (*80*) reported that at the one-tenth bloom stage white clover generally contained a higher percentage of each of 16 amino acids than birdsfoot trefoil, alfalfa, or red clover. Their analyses of the spring growth of Ladino clover and alfalfa in 1959 and 1960 are given in table 2.

TABLE 2.—*Dry-weight concentration of amino acids in Ladino clover and alfalfa*

Amino acid	Ladino clover		Alfalfa	
	1959	1960	1959	1960
	Percent	*Percent*	*Percent*	*Percent*
Alanine	1.24	1.15	0.80	0.80
Arginine	.86	1.27	.71	.86
Aspartic acid	2.04	3.00	1.43	2.27
Glutamic acid	2.19	1.65	1.43	1.42
Glycine	1.25	1.06	.75	.78
Histidine	.43	.58	.34	.41
Isoleucine	1.05	1.15	.67	.72
Leucine	1.88	1.77	1.15	1.25
Lysine	.54	1.54	.72	1.09
Methionine	.37	.29	.20	.23
Phenylalanine	1.21	1.14	.80	.83
Proline	1.05	.98	.75	.75
Serine	.94	1.00	.70	.78
Threonine	1.03	1.18	.74	.83
Tyrosine	.85	.85	.50	.58
Valine	1.29	.56	.93	1.01
Crude protein	22.63	24.88	16.31	19.50

The total sugar content has been found to be over 12 percent. The phosphorus, calcium, and potassium contents are over 0.35, 1.50, and 1.50 percent, respectively (*85*). Vitamins of the B complex, C, E, K, and provitamin A are present in fresh white clover in sufficient quantities to supply animal requirements. Trace elements are usually present in sufficient amounts, particularly when the plants are grown in soils where these are not deficient. Otherwise, these elements should be added as supplements in the feed.

Coumestrol, a natural estrogen, was first isolated from white clover (*20*). Variety, stage of maturity, and environment appear to affect the quantity. Coumestrol of white clover may be a quality factor in feed for certain kinds of livestock and poultry. It may be more than of academic interest to note the similarity in molecular structure of coumestrol and diethylstilbestrol and their beneficial effect on milk and meat production. Coumestrol in excess may also be objectionable, causing infertility in animals.

The presence of HCN (hydrocyanic acid) in white clover has been known for many years (*87*). The plants contain the cyanogenetic glucosides lotaustralin and linamarin and the hydrolyzing enzyme linamarase resulting in the formation of HCN (*35*, *36*). The amount of HCN varies widely depending on genotype, stage of maturity, and environmental factors. Even with a relatively high concentration in the white clover plant, HCN has not proved to be toxic to animals or poultry. Ladino clover is free of or low in HCN, whereas New Zealand white clover is high. The presence of HCN in New Zealand white clover appears to be the reason for its resistance to slugs or snails, which greatly injure Ladino. The presence of these substances may be the reason for the reported salivation of horses grazing white clover, although no evidence has been presented on this point.

Saponins and sapogenins are present in white clover. The number and their identity are not known. At one time they were considered to be the principal cause of bloat in ruminating animals (*43*). Further investigations have not substantiated the earlier conclusion. They may affect the incidence of bloat or they may not be associated with it.

BLOAT

White clover is one of many legumes that cause bloat of cattle and sheep (*43*). Lush forage appears to be more incitive than older leaves. However, Ladino clover pastures under irrigation may cause bloat at any time. The causes of bloat are not known. Pasture bloat and dry-lot bloat are two kinds. Because of its high nutritive value, white clover is a concentrated feed and may induce bloat when consumed in large amounts. Many livestock producers believe that a mixture of 50 percent clover and 50 percent grass is the solution. Such a mixture may be less likely to bloat animals, but the authors have seen animals preferentially graze the clover fraction of the mixture with disastrous results.

Many livestock producers claim a reduction in the bloat hazard by keeping racks of dry straw or coarse grass hay in every field readily available to the grazing animals. Antibiotics, antifoaming agents, and different methods of grazing have been tried with variable results. Precautions should be taken to reduce the incidence of bloat and provision made to cope with it when it occurs. The recommendations of the State agricultural experiment stations on the use of antibiotics and antifoaming agents and on the feeding of oils and fats to control bloat should be followed.

The following practices may be helpful in reducing the incidence of bloat:

(1) Feed animals straw or grass hay before turning them out on lush clover pasture.

(2) Keep racks of dry straw or grass hay readily available in every pasture.

(3) Plant mixtures of grass and clover. Choose a grass that has the same season of growth as the clover.

(4) Keep grass highly palatable by frequent clipping if animals preferentially graze clover.

(5) Use intensive grazing to prevent the accumulation of excessive amounts of lush forage.

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